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Shallow-Water Acoustics Investigations for Underwater Detection and Seabed Imaging

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Abstract- This paper is concerned with the problem of recognition of objects laying on the seabed and presented on echosounder images. Considering that high resolution echosounder system provides acoustic images of high-quality, this research have been interested in shallow water investigations for underwater objects. This work presented recent detection algorithms for coral reef, seagrass, and seabed using signal processing. Acoustic reflectivity and backscatter strength of coral reef were higher than seagrass. The lifeform of coral reef had different acoustic intensity value.

Keywords: acoustics, signal, processing, underwater, detection, classification, imaging, seabed

Introduction

Propagation of acoustic wave in shallow-water had been studied for a long time (Waite, 2002). Their applications are to detect fish, submarine, underwater communication, and mines (Abraham et al, 2002). Research using shallow-waters acoustics were complicated because in the water column inhomogenous produces a mode coupling which can induce significant effects over large propagation distances (Ainsle, 2010).

Sonar is a general term for any instrument that uses sound for remote detection of underwater objects (Haykin, 1985). Active sonar system generate short bursts (pings) of high frequency sound. These acoustic waves are emitted by the transducer into the water column and seabed (Burdic, 1984, Manik, 2015). The returned echo was measured with four quadrants in the split beam transducer. For a monostatic sonar, which has co-located transmitter and receiver, directivity of transducer describes the dependence of backscatter on the angle between the incident acoustic wave and a target (MacLennan and Simmonds, 2003, Manik et al 2015).

Coral reef is an important component of marine ecosystems that support a number of commercially important fisheries (Deegan, 2002). Many of the habitat requirements of coral reef can be disrupted by human activities, and loss of coral reef habitat can often be attributed to anthropogenic causes (Short and Wyllie-Echeverria, 1996). Recent worldwide losses in coral reef habitat have caused many government agencies and environmental groups to develop monitoring programs for this important coastal resource.

The need to monitor coral reef has led to the use of numerous methods for assessing its distribution and attributes, includingdiving-based surveys, aerial photography, and underwater video (Duarte and Kirkman, 2001). Underwater video data have been used in monitoring programs to estimate areal coverage of subtidal aquatic vegetation in Seribu Island (Manik, 2012). Underwater video data provide an unambiguous assessment of coral presence, but quantitative information other than presence or absence is very difficult to extract. Recently, there has been extensive research into using acoustic devices, such as single-beam sonar (Sabol and others, 2002), multibeam sonar (Komatsu et al, 2003), and acoustic Doppler current profilers (Warren and Peterson, 2007) to quantify coral reef habitat.

However, the accuracy of acoustically derived coral reef maps can be lower than those created with underwater video because of errors associated with interpreting and classifying acoustic data. With a few exceptions (for example, Winfield and others, 2007), the accuracy of acoustically derived plant attributes is either not determined or not reported.

We describe data-collection and analysis methods for characterizing coral distribution using a splitbeam echosounder and their applications in Seribu Islands waters. Underwater video was collected simultaneously with the acoustic data in a subset of the acoustic survey lines.

Material and Methods

Echosounder data was collected by underwater acoustic survey in Pramuka Island seawaters. We conducted 5 stations (Sta.) for acoustic sampling and grounth truth. The primary components of the acoustic survey equipment were a deck unit, a laptop computer, transducers, and a real-time kinematic global positioning system (GPS). The transducers used in this survey were 120 kHz Biosonics DT-X series digital transducers with beam width of 6 degrees. The ping rate for this transducers was set to 5 Hz (100-ms intervals), and the duration of each pulse was 0.4 ms. The operating range of both transducers was set to 40 m. Control of the transducers and a real-time display of the output from the system was achieved through Biosonics acquisition software installed on a laptop personal computer (PC). The laptop PC was connected through an Ethernet cable to a deck unit that sends and receives signals from the transducers and integrates data from the echo sounder with available external sensors such GPS. Return echoes from the transducers were digitized by a dedicated processor in the deck unit at 50 kHz, leading to an approximate vertical resolution of 1.8 cm. The horizontal and vertical positions of the transducers were determined using a real-time kinematic global positioning system (RTK GPS).

For data processing, sonar data is computed using image analysis. Image analysis is a relatively new expertise developed along with the development of the computer (Minkoff, 2002). A typical image analysis system consists of four main steps. These are image enhancement, segmentation, shape analysis, and classification (Pratt, 1991). Image enhancement involves filtering. Low-pass filters can remove high frequency noise while high-pass filters can be applied to enhance edges (Marage and Mori, 2010). Many types of filters exist like convolution-based finite impulse response (FIR), infinite impulse response (IIR) windowing by masks, and algorithm-based filters (Richards, 2010). Other types of filters are based on transformation to the frequency domain by e.g., Fourier analysis. Transformation into the frequency domain enables filtering with sampled versions of analogue filters (Balk and Lindem, 1998). Segmentation is the process of classifying pixels in an image. Classification criteria can be found in features connected with each pixel such as colour or intensity. Different segmentation methods are available. The most common methods are the threshold and the edge detection method. With the edge detection method, edges from the objects are detected with high-pass filters.

Sonar signal processing was conducted by computing the sonar equations. The sonar parameters were source level, sound spreading and attenuation, transmission loss, target strength, noise level, and array gain (Urick, 1983). Block diagram of shallow water acoustic system was shown in Fig. 1. The sonar transmits a signal with a source level SL, given in underwater dB one meter from the source. The energy of sound becomes weaker due to geometrical spreading and sound absorption and calculated by transmission loss TL. The sound intensity level (SIL) at the target is (SL -TL) decibels. The echo from the target calculated by this equations below (Urick, 1983) :

$$SIL \text{ (decibels)} = SL - TL + TS \quad (1)$$

The intensity of echo at the receiver is then:

$$EL \text{ (decibels)} = (SL - TL) + TS - TL \quad (2)$$

which can be simplified to:

$$EL \text{ (decibels)} = SL - 2TL + TS \quad (3)$$

Signal-to-noise ratio (SNR) was measured by, is:

$$SNR \text{ (decibels)} = SL - 2TL + TS - NL \quad (4)$$

By using array gain AG, the SNR was increased :

$$SNR \text{ (decibels)} = SL - 2TL + TS - (NL - AG) \quad (5)$$

$$SV \text{ (dB)} = 20 \log \text{(counts)} - SL - RS - C + PS + TVG_{Sv} + \text{Calibration Sv} \quad (6)$$

$$TS \text{ (dB)} = 20 \log \text{(counts)} - SL - RS + PS + TVG_{TS} + \text{Calibration TS} \quad (7)$$

$$TVG_{Sv} = 20 \log R + 2\alpha R \quad (8)$$

$$TVG_{TS} = 40 \log R + 2\alpha R \quad (9)$$

where R is the range from the transducer. TVG is applied when range is greater than 1 meter. α is the absorption coefficient.

$$C = 10 \log (c\, \tau\, \psi / 2) \quad (10)$$

where c = sound speed (m/s), τ = the pulse length (s), ψ = the equivalent two-way beam angle (steradians),

Implementation of filter techniques based on convolution. A picture can be expressed mathematically by the two-dimensional shift integral. This integral integrates the product between the image function F and a delta Dirac function (Balk and Lindem, 2000).

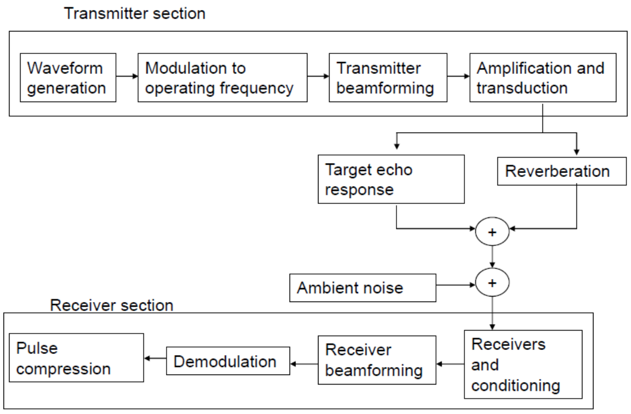


Fig. 1. Block diagram of shallow water acoustics system

Results

A split beam sonar works by emitting a short burst of sound (ping) towards the sea bottom and recording reflected sound (echoes). Directivity pattern of transducer was shown in Fig. 2. The strength of reflected sound (backscatter or echo intensity) was recorded at a series of time intervals, resulting in a profile of acoustic backscatter versus time. The distance between the transducer and objects in the water (range) was calculated based on the speed of sound in sea water. As the ship navigates along survey lines, data from multiple pings are recorded, resulting in a two-dimensional picture of backscatter strength. Examples of first and second bottom echoes were shown in Fig. 3. Acoustic data from a Biosonics DT-X series echo sounder were analyzed to determine the sea-floor and the presence or absence of target. The analysis was performed on each ping, and relies on distinct differences in the acoustic backscatter signal from vegetated and coral reef surfaces. The signal-processing technique described here is based on an algorithm described in Biosonics (2004a). Before classification of the acoustic data, raw backscatter data were converted to backscatter strength in decibels (dB) or volume scattering strength (in dB) using equations 4a and 4b in Biosonics (2004b). Both of these common acoustic quantities remove the effect of sound attenuation in seawater by applying a time-varied gain to the raw acoustic backscatter amplitude. The absorption, or attenuation coefficient (dB/m), was calculated using the equations given in Francois and Garrison (1982) and surface the temperature and salinity values measured during the survey.

The sonar image and separation of noise were shown in Figs. 4 and 5, respectively. The result of applying a 3x3 mean filter was shown in Figure 6.

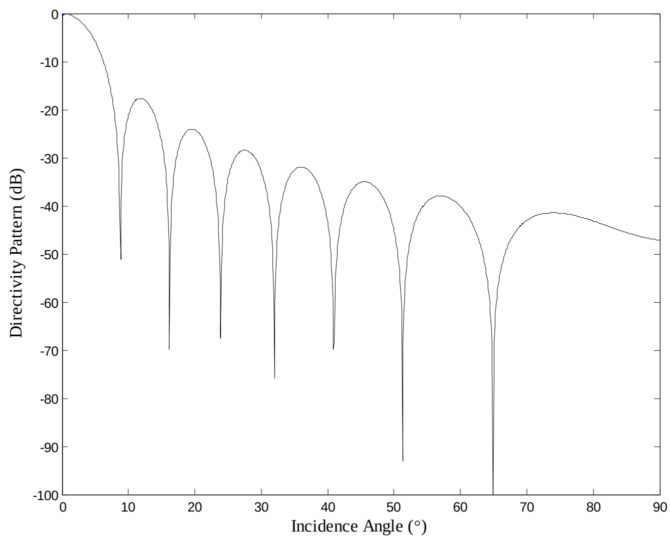


Fig. 2. Directivity pattern of underwater transducer.

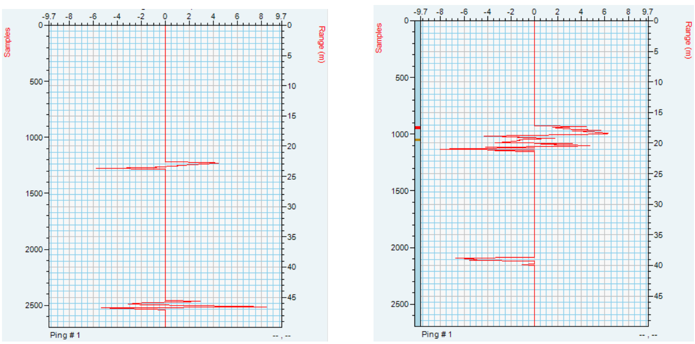


Fig. 3. Examples of first and second bottom echo.

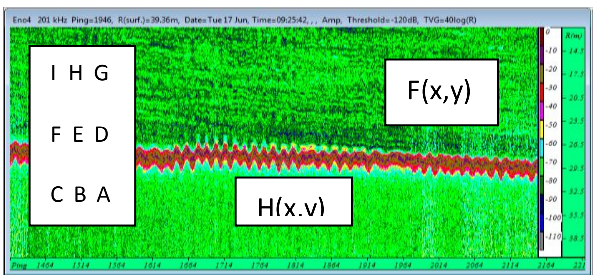


Fig. 4. The echogram image represents the input function F(x,y) while H(x,y) represents the impulse response matrix.

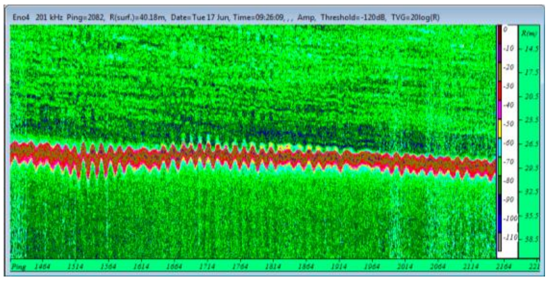


Fig. 5. Noise separation of echogram image

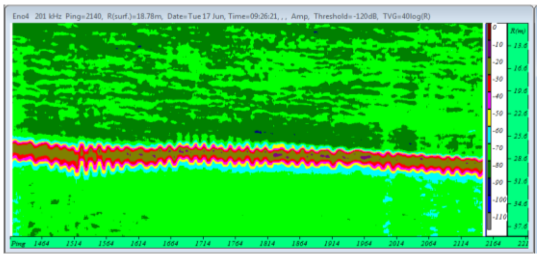


Fig. 6. Output echogram image G(x,y)=F(x,y) ⊗ H(x,y).*F* is the sonar image seen in Figure 5 and *H* is a 3x3 lowpass mean filter.

Selection of filter size and filter coefficients is important. The red color is sea bed while the green color is underwater target such as zooplankton. While one set of coefficients will result in a low-pass filter, a different set can result in a high-pass filter. Target detection and its histogram were shown in Figs. 7 and 8. Figures 9 shows the application of sonar signal processing for shallow waters to detect coral reef, seagrass, and seabed. The left side was the sonar image with *y* axis represent the amplitude intensity and *x* axis represent the ping number. The right side was underwater video camera correspond with each sonar image.

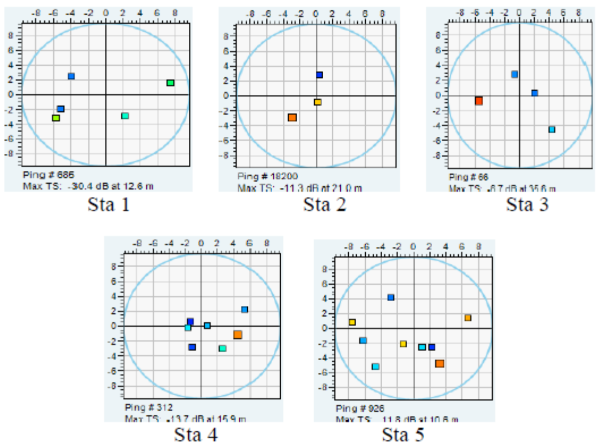


Fig. 7. Underwater target detection in sound beam at Sta 1 to Sta 5, consecutively.

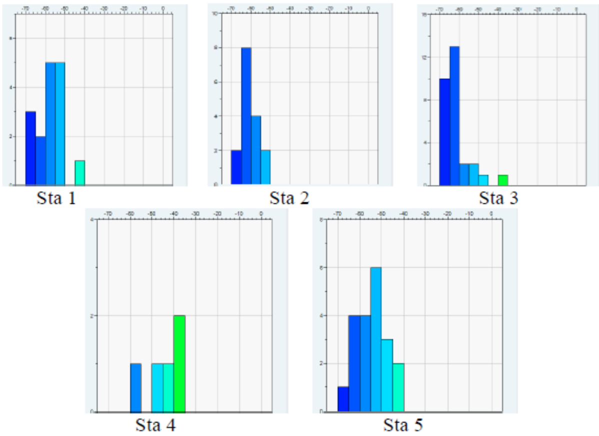
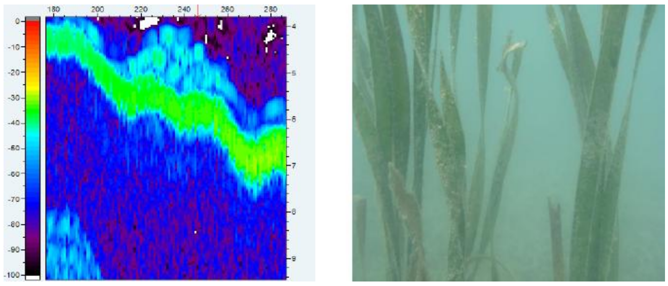


Fig. 8. Histogram of Target Strength for each station



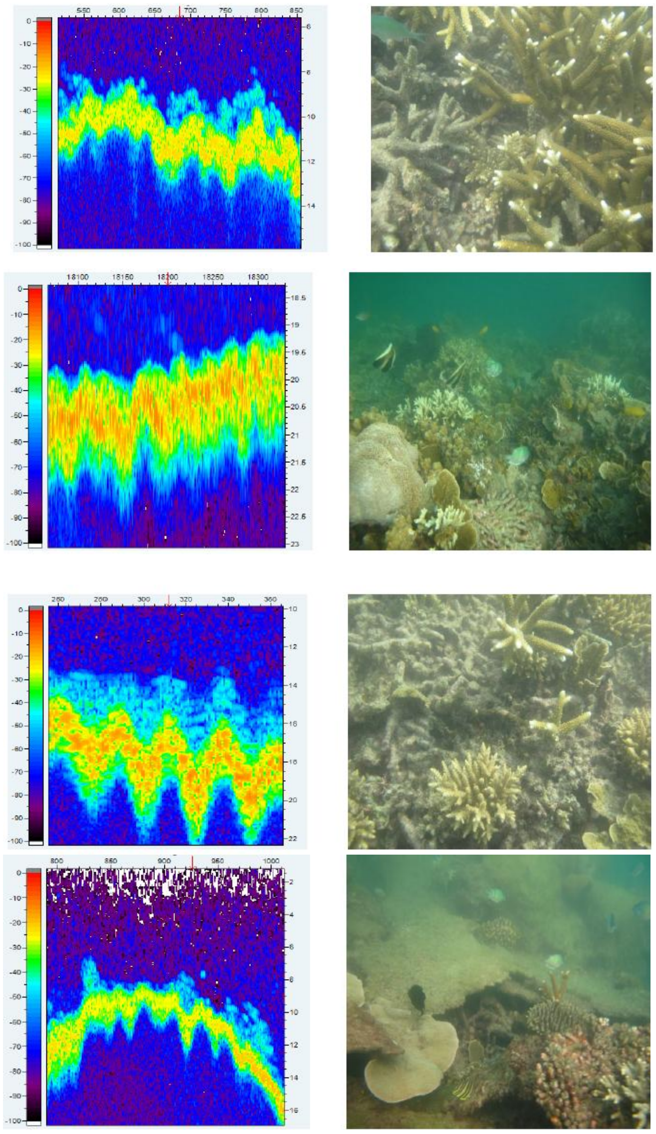


Fig. 9. Shallow water imaging and underwater video from Sta. 1 to 5, consecutively.

The amplitude intensity ranged from -29.0 dB to -10.0 dB for coral reef and -40.0 to -30.0 dB for seagrass. The lifeform of coral reef consisted of Acropora Digitate (Sta 1 and 3), foliose and massif coral (Sta 2) and Acropora tabular (Sta 4). The reflectivity and backscatter value of coral reef were higher than seagrass (Fig. 10 and 11). The reason was the acoustics impedance value of coral reef was higher than seagrass. The other reason was the roughness of coral reef also higher than seagrass. The reflectivity and backscattering strength was depend also on target orientation relative to transducer position. Histogram of single echo detector (SED) were ranged from -70.0 to 0.0 dB for all station (Fig. 12). The backscatter strength of seabed ranged from -30.0 to -20.0 dB at Sta 1, -35.0 to -15.0 dB at Sta 2, -35.0 to -20.0 dB at Sta 3, -35.0 dB to -28.0 dB at Sta 4, and -40.0 to -35.0 dB at Sta 5. According to Manik (2010), this backscattering value indicate the seabed type from silt, clay, and sand. By sonar signal processing, the classification of underwater target was possible. Balk and Lindem (2010) developed SED for fish detection. The highest SED detected 25 % at Sta 2 and 3 while the lowest SED was 12 % at Sta 5. We suggested in the future, research on SED analysis should be conducted for easy interpretation of shallow water environment.

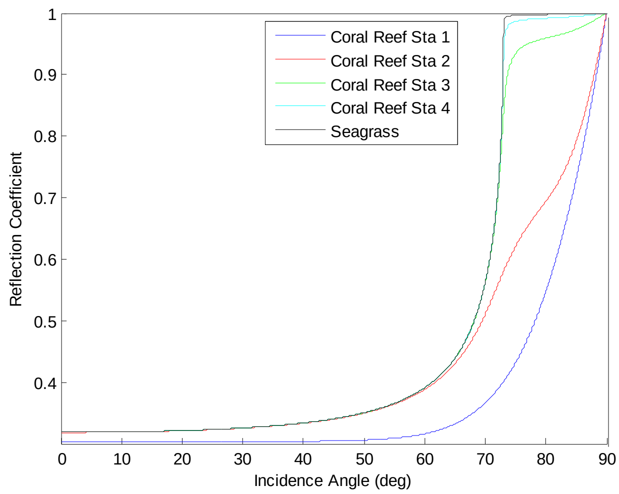


Fig. 10. Acoustic Reflection of Underwater Objects

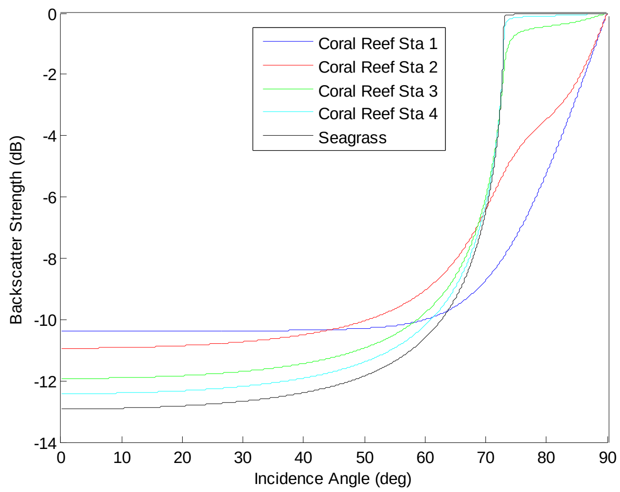
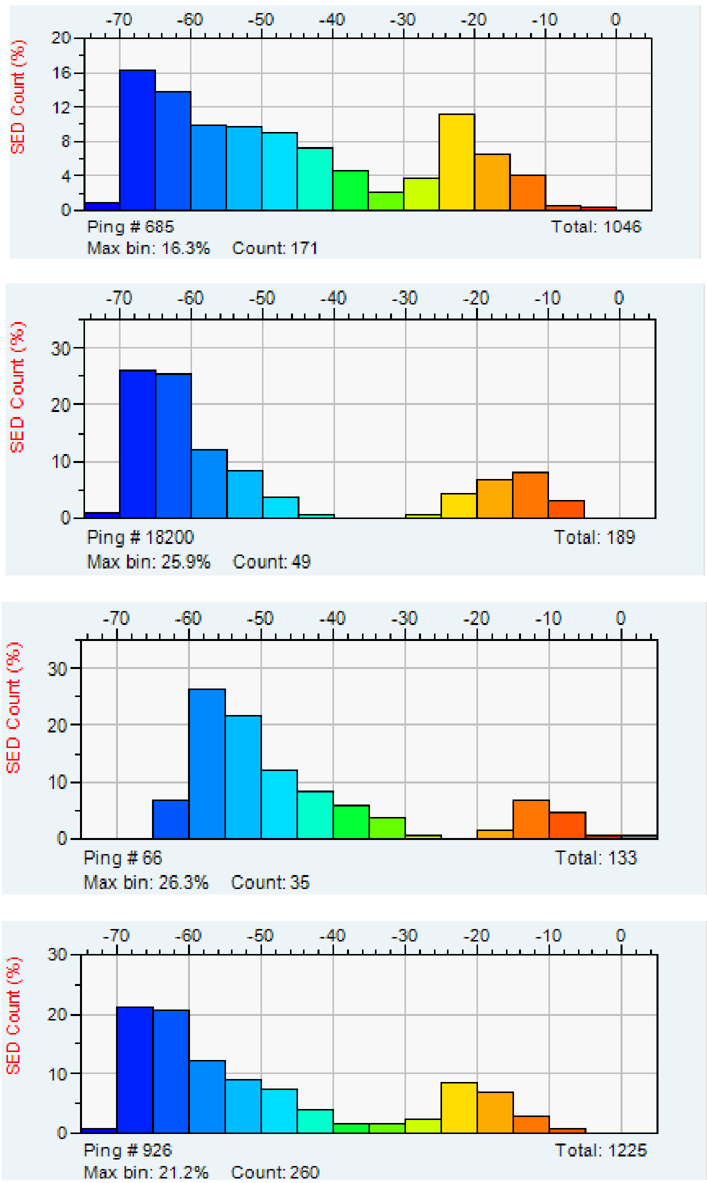


Fig. 11. Acoustic Backscattering of Underwater Objects.



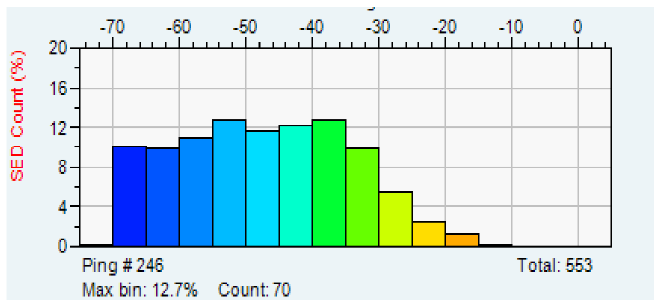


Fig. 12. Single Echo Detector Echogram for Sta 1 to 5, consecutively.

Conclusion

This study had shown that a split-beam echosounder can accurately detect and classify underwater targets. Classification of split-beam acoustic data for coral reef and seagrass was simple, fast, and intuitive relative to other mapping techniques. In areas where more than one type of coral reef was present, underwater video of ground-truth data was needed in order to accurately interpret the acoustic data. We conclude that classification algorithms should be fully automated. Comparison of underwater video and acoustic data collected simultaneously at this site showed that classification of the acoustic data was highly accurate for determining the presence or absence of coral reef. Acoustic methods have a much greater potential for measuring percent cover than underwater video, because the high spatial resolution of the sampling. Another benefit of acoustic methods is the ability to survey in turbid areas, where the area with minimum visibility.

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